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Effect of loading rate and pre-heating time on the strength properties of African nutmeg (*Monodora myristica*)

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Abstract. In this work, the effect of loading rate and pre-heating time on African nutmeg seed coat was investigated as it affects compressive force, deformation, failure stress, strain energy and modulus of elasticity. Compressive tests were conducted at loading rates of 1, 2.5, 4, 5.5 and 7 mm min^{-1} at a moisture content of 14%. Further tests were carried out at pre-heating times of 10, 20, 30, 40 and 50 min at a constant temperature of 180°C. Results show that force required to crack open the seed coat varied from 27.08 to 53.6 N at loading rates of 1 and 7 mm min^{-1}, respectively. Also, compressive force decreased from 61.46 to 47.04 N at 10 mm and 50 min of pre-heating, respectively. Deformation of seed coat showed a positive trend as it increased from 0.464 to 0.757 mm at 1 and 7 mm min^{-1}. Strain energy was found to be 0.0082 Nmm at 1 mm min^{-1} and 0.0266 Nmm at 7 mm min^{-1}.

Keywords: African nutmeg, loading rate, pre-heating time, strength properties

INTRODUCTION

Morphologically, African nutmeg (*Monodora myristica*) is a berry classed in the Anannacea family of tree crops. It is known to thrive well in the tropical forests of Africa, most especially in the Southern part of Nigeria. The seeds are embedded in white sweet-smelling pulp of the sub-spherical fruit (Fig. 1) and are economically and nutritionally essential (Burubai, 2007). The kernel obtained from the seeds is a widely accepted spicing agent in both African and continental cuisines. When ground to powder, it is used to prepare pepper soup as a stimulant to relieve constipation and control passive uterine hemorrhage in women immediately after child birth (Udeala, 2000). In spite of its relevance, the cracking of the seed coat to extract the kernel is yet to be mechanized. This energy-demanding and time-consuming unit operation can be positively manipulated by varying the loading rate and pre-heating time to condition the seed for mechanized cracking.

Biological materials as composed primarily of polymeric substances, holding varying amounts of water, and responding to mechanical loading inputs are characterized in a manner called viscoelastic (Fridley *et al*., 1968). This unique behaviour has rendered biomaterial loading rate sensitive (Mohsenin, 1970). This has prompted the investigation of the effect of loading rate on agricultural materials. Khazaei and Mann (2004) studied the effect of loading rate on puncture force and energy for sea buckthorn berries at loading rates of 0.3, 1.5, 3.5, 6 and 9 mm s^{-1} at a constant berry temperature of 16.5°C. They observed that puncture force and energy increased with increasing loading rate.

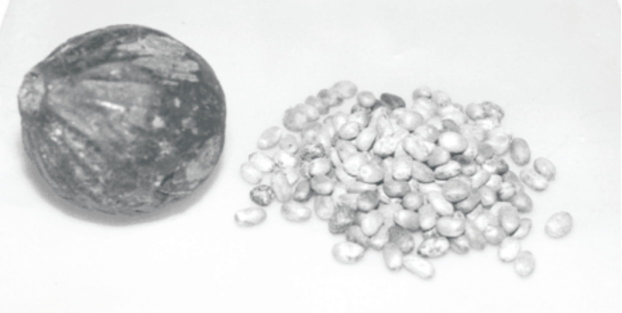

Fig. 1. Fruit and seeds of African nutmeg.

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On the other hand, the softening phenomenon that occurs in plant materials upon heating has been attributed partly to the loss of turgor pressure and chemical changes in the cell wall (Van Buren, 1979). A reaction of particular importance with regard to the texture of heated fruits is the depolymerisation of pectic substances (Anderson *et al*., 1994). Ramana *et al*. (1992) studied the cellular integrity of biomaterials during heating by microscopic examination. They observed that cellular integrity was lost between 50 and 65°C. They also concluded that loss of cellular integrity is also a function of the exposure time of the sample to heat.

Therefore the objective of this study was to investigate the effect of loading rate and pre-heating time on the strength properties of African nutmeg.

MATERIALS AND METHODS

Samples of fresh African nutmeg fruits were obtained from the Sabagreia forest, Nigeria, on the 30th July 2006. Seeds were processed and stored at 0°C and 90% relative humidity as a conditioning measure before use.

Loading rate tests were conducted at 1, 2.5. 4, 5.5 and 7 mm min^{-1} at a moisture content of 14% (d.b.) as recommended by ASAE S368.4 (2000) and as was used by Khazaei and Mann (2004) in investigating the mechanical properties of sea buckthorn berries. Ten samples were tested at each of the selected loading rates. Quasi-static compression was performed at the above stated loading rates with the individual seeds axially loaded between the two parallel plates of the universal testing machine. As compression progressed, data on the strength properties of the sample were obtained from the recorder.

The time-temperature dependence in the pre-heating process and how these can affect the mechanical behaviour of African nutmeg was investigated at a temperature of 180°C at intervals of 10, 20, 30, 40 and 50 min. Prior to testing, the samples were held at a moisture content of 14 percent (d.b.). A temperature controlled heating rig (model TLI, NCAM, Nig) with a cylindrical barrel heating chamber was used. A pre-set temperature of 180°C was selected from the thermostat and allowed to stabilise before inserting the samples. Ten samples were then pre-heated at each of the time intervals for the constant temperature of 180°C. At the expiration of every time interval, pre-heated samples were immediately removed and compressed with the universal testing machine at a loading rate of 2.5 mm min^{-1} in accordance with the recommendations of ASAE S368.4 (2000) to obtain the effect of pre-heating time on the strength properties of the specimen. These data were obtained directly from the integrator.

RESULTS AND DISCUSSION

Compressive force

The effect of loading rate on the force needed to cause the required seed coat rupture is shown in Table 1. At 1 mm min^{-1}, a compressive force of 27.08 N was obtained. It then increased to 53.6 N at 7 mm min^{-1}. However, the highest force of 56.6 N was recorded at 2.5 mm min^{-1}. Therefore it could be deduced that compressive force increased with increase in loading rate. Thus confirmed the works of Khazaei and Mann (2004). The regression between force and load rate is shown in Fig. 2a. Besides, the effect of pre-heating time on force causing seed coat rupture is given in Table 2. The results reveal that, generally, the compressive force decreased as pre-heating time increased. Compressive force value varied from 61.46 to 39.16 N for pre-heating times of 10 and 40 min, respectively. This then increased to 47.04 N at 50 min. The regression relation between force and pre-heating time is shown in Fig. 2b.

Deformation

Values on the effect of loading rate on deformation are given in Table 1. The data reveal deformation values of 0.464 mm at 1 mm min^{-1} to 1.074 mm at 2.5 mm min^{-1}. This then decreased to 0.758 mm at 7 mm min^{-1}. The trend between deformation and loading rate is shown in Fig. 3a.

On the other hand, the deformation values changed from 0.823 mm to 0.564 at pre-heating times of 10 min and 50 min, respectively. These results are in conformity with the findings of Bourne (1982) and Vincent (1999). The correlation between deformation and pre-heating time is shown in Fig. 3b.

Failure stress

Information on the variation of failure stress as a function of loading rate is presented in Table 1. The data reveals a sharp increase in failure stress from 2.87 to 5.99 N mm^{-2} at 1 to 2.5 mm min^{-1}. It then declined to 5.6 N mm^{-2} at 7 mm min^{-1}. These results confirm the fact that increase in loading rate is attended by an increase in failure stress. The correlation between loading rate and failure stress is presented in Fig. 4a.

In addition, failure stress value decreased from 6.5 to 4.178 N mm^{-2} from a pre-heating time of 10 to 50 min, respectively, as shown in Table 1. This negative trend in results confirms the fact that increase in pre-heating time reduces the cellular integrity of biomaterials (Ramana *et al*., 1992). The regression-type behaviour between failure stress and pre-heating time is given in Fig. 4b.

Table 1. Effect of loading rate on strength properties

Loading rates (mm min^{-1})	Strength properties	Range	Mean	Standard deviation
1.0	Compressive force (N)	45.00-11.10	27.08	10.89
	Deformation (mm)	0.7960-0.2390	0.4643	0.2064
	Failure stress (N mm^{-2})	4.762-1.175	2.866	1.153
	Strain energy (N mm)	0.0217-0.0012	0.0082	0.0066
	Young's modulus (N mm^{-2})	203.74-68.71	115.51	39.47
2.5	Compressive force (N)	96.20-27.60	56.49	20.49
	Deformation (mm)	2.312-0.494	1.0738	0.5177
	Failure stress (N mm^{-2})	10.180-2.921	5.989	2.168
	Strain energy (N mm)	0.1168- 0.0078	0.0401	0.0308
	Young's modulus (N mm^{-2})	167.19-69.44	120.59	30.58
4.0	Compressive force (N)	80.90-17.20	46.84	18.97
	Deformation (mm)	1.4210-0.2690	0.8219	0.4152
	Failure stress (N mm^{-2})	8.561-1.820	4.9566	2.008
	Strain energy (N mm)	0.0590-0.0026	0.0252	0.0199
	Young's modulus (N mm^{-2})	221.23-3.13	125.21	54.84
5.5	Compressive force (N)	85.50-1830	54.44	29.26
	Deformation (mm)	1.3750-0.3340	0.7757	0.3616
	Failure stress (N mm^{-2})	9.048-1.937	5.761	3.097
	Strain energy (N mm)	0.064-0.0037	0.0303	0.030
	Young's modulus (N mm^{-2})	212.48-63.25	136.13	38.85
7.0	Compressive force (N)	85.50-1830	53.60	24.44
	Deformation (mm)	1.3750-0.3340	0.7579	0.4280
	Failure stress (N mm^{-2})	9.048-1.937	5.672	2.586
	Strain energy (N mm)	0.064-0.0037	0.0266	0.0229
	Young's modulus (N mm^{-2})	212.48-63.25	128.46	53.74

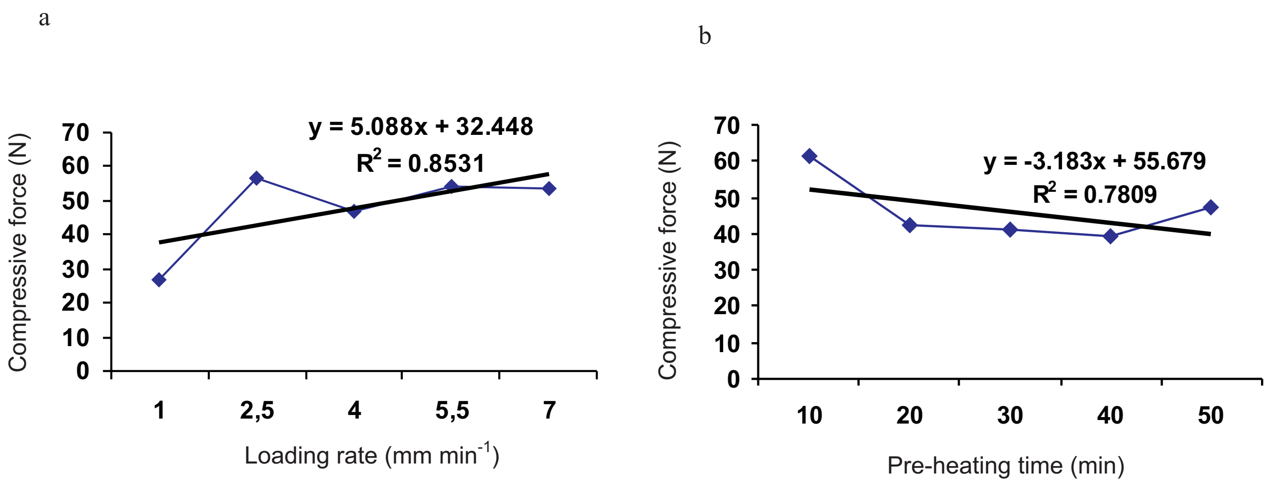

Fig. 2. Effects of: a – loading rate and b – pre-heating time on force.

Table 2. Effect of pre-heating time on strength properties

Pre-heating time (min)	Strength properties	Range	Mean	Standard deviation
1.0	Compressive force (N)	139.40-15.70	61.46	42.24
	Deformation (mm)	1.977-0.149	0.823	0.506
	Failure stress (N mm^{-2})	14.75-1.661	6.50	4.47
	Strain energy (N mm)	0.0716-0.0014	0.0304	0.0236
	Young's modulus (N mm^{-2})	411.67-57.38	166.23	96.27
20	Compressive force (N)	60.9-20.0	42.15	13.55
	Deformation (mm)	0.562- 0.2880	0.459	0.092
	Failure stress (N mm^{-2})	6.444-2.116	4.460	1.434
	Strain energy (N mm)	0.0192-0.0037	0.0115	0.0046
	Young's modulus (N mm^{-2})	240.14-199.25	127.55	42.04
30	Compressive force (N)	85.7-17.8	40.84	21.235
	Deformation (mm)	0.913-0.3040	0.548	0.184
	Failure stress (N mm^{-2})	9.069-1.884	4.322	2.247
	Strain energy (N mm)	0.0344-0.0031	0.034	0.0096
	Young's modulus (N mm^{-2})	170.4-5364	12.11	20.43
45	Compressive force (N)	61.4-5.2	39.16	17.15
	Deformation (mm)	1.741-0.100	0.609	0.448
	Failure stress (N mm^{-2})	6.49-0.550	4.143	1.815
	Strain energy (N mm)	0.047-0.002	0.0149	0.0136
	Young's modulus (N mm^{-2})	213.32-29.56	141.06	50.41
50	Compressive force (N)	89.00-23.20	47.04	21.41
	Deformation (mm)	1.215-0.136	0.564	0.0281
	Failure stress (N mm^{-2})	9.418-2.455	4.178	2.266
	Strain energy (N mm)	0.0334-0.0018	0.0150	0.0019
	Young's modulus (N mm^{-2})	337.54-84.91	181.46	76.31

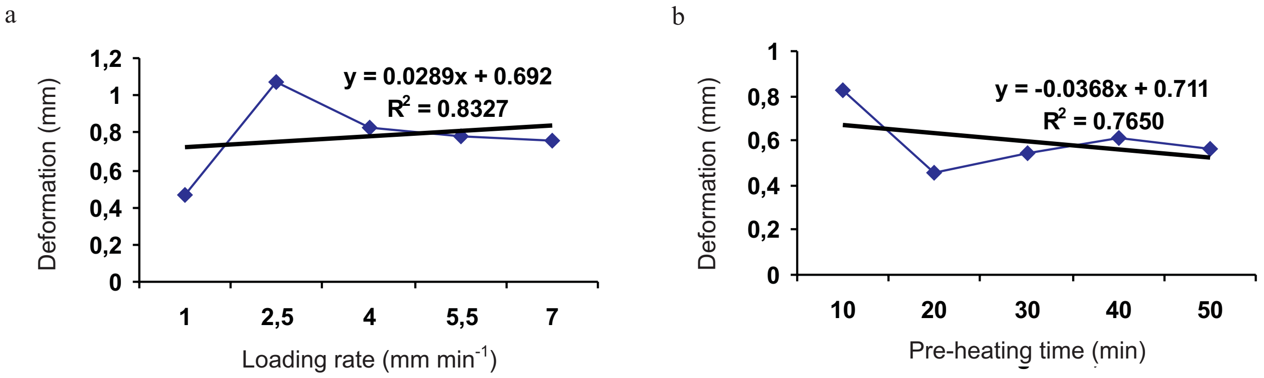

Fig. 3. Effects of: a – loading rate and b – pre-heating time on deformation.

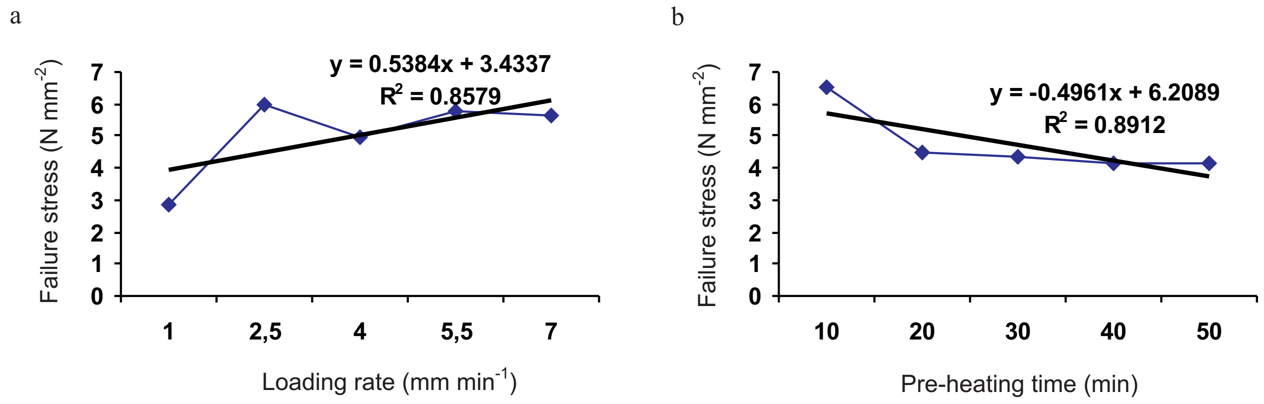

Fig. 4. Effects of: a – loading rate and b – pre-heating time on failure stress.

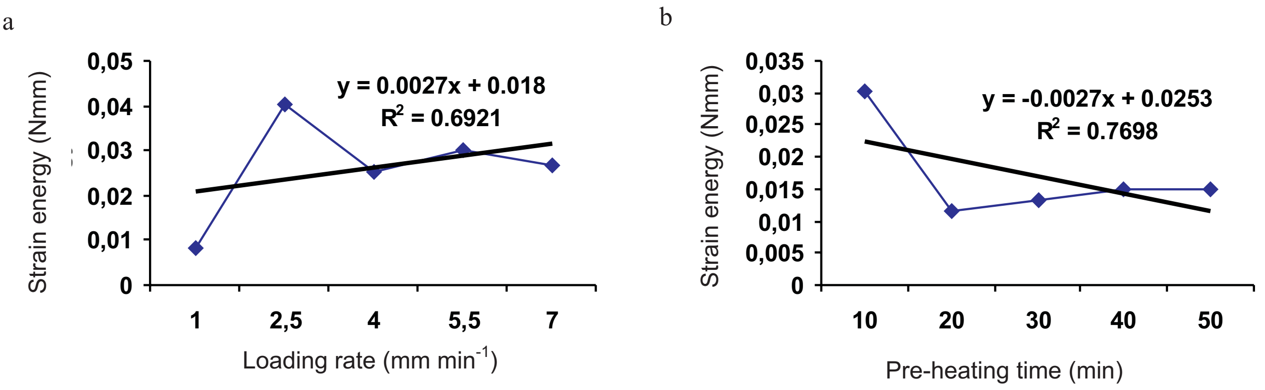

Fig. 5. Effects of: a – loading rate and b – pre-heating time on strain energy.

Strain energy (toughness)

Tables 1 and 2 present the data on strain energy as a function of both loading rates and pre-heating time of the specimen. Generally, strain energy is observed to decrease with an increase in loading rate. An average value of 0.0082 Nmm was obtained at 1 mm min^{-1} and 0.0266 Nmm at 7 mm min^{-1}. This trend is shown in Fig. 5a.

On the other hand, a strain energy value of 0.0304 Nmm was recorded at 10 min of pre-heating time. It then declined to 0.015 Nmm at 50 min of pre-heating. The results, therefore, reveal that at longer pre-heating times the African nutmeg seeds absorb lesser energy, thus confirming the investigation of Shomer (1995) on tomatoes. This correlation is presented in Fig. 5b.

Young's modulus

The effect of loading rates and pre-heating time on the Young's modus of African nutmeg is given in Tables 1 and 2.

The results show that, generally, Young's modulus increases with an increase in loading rate. At 1 mm min^{-1}, an average value of 115.5 N mm^{-2} was observed. This value increased to 128.46 N mm^{-2} at 7 mm min^{-1}. This positive behaviour is shown in Fig. 6a.

Furthermore, the effect of pre-heating time on average values of Young's modulus is presented in Table 2 and in Fig. 6b. At 10 min, an average Young's modulus value of 166.23 N mm^{-2} was recorded, but increased to 181.46 N mm^{-2}. This increase may be attributed to the case hardening effect of the seeds after prolonged pre-heating.

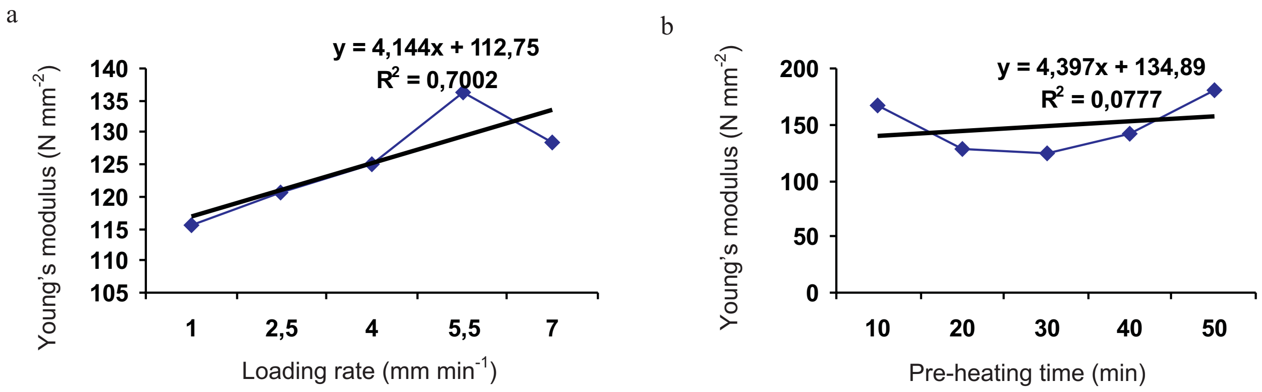

Fig. 6. Effects of: a – loading rate and b – pre-heating time on Young's modulus.

Engineering implications

Cracking of African nutmeg is the most serious problem encountered in the processing of this nutritionally and medically viable crop. Thus the data provided herein, if properly utilized, could save energy and enhance its mechanization process.

CONCLUSIONS

1. An average compressive force of 27.08 to 53.6 N was recorded at 1 and 7 mm min^{-1}. However, to avoid excessive kernel breakage, cracking should be conducted at loading rates of 1 and 2.5 mm min^{-1}. Also, the pre-heating time of 10 min is recommended.

2. Deformation, being the desired parameter, tends to be acceptable at a loading rate of between 1 and 2.5 mm min^{-1} at a pre-heating time of 10 min.

3. Failure stress tends to increase with loading rate but declines with an increase in pre-heating time.

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